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Ecological Nature in Rural Architecture in Xi'an

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ABSTRACT

Exploring the ecological nature of rural architecture is significant for promoting sustainable development in rural areas. By studying the ecological nature of rural architecture, it can drive the development of rural buildings towards environmental protection, energy conservation, and resource recycling, reducing negative impacts on the environment and improving the quality of rural life. Taking Nandoujiao Village in Xi'an as an example, this article investigates the ecological nature of rural housing in Xi'an and its surrounding areas through field research, literature review, comparative analysis, case study, historical analysis and deduction. At the architectural design level, the buildings exhibit strong defensive and inward characteristics, with their layouts largely following the traditional style of rural housing in the Guanzhong region. Technologically, rammed earth walls are used, which have environmentally friendly, durable, and good thermal insulation properties, employing an ancient construction technique that involves compacting soil and stones. In terms of plant cultivation, a wide variety of plants are chosen for greening the residential courtyards, with the selection of plant species adapted to the local climate and a preference for fruit-bearing trees. The choice of plant species and planting methods also align with the residents' needs and habits, while also incorporating sun shading and courtyard ventilation in the summer, creating a comfortable green environment. In terms of water utilization, the buildings enhance drainage through roof water collection, eaves components for water diversion, and drainage channels. Water storage is increased through the use of water jars, water wells, and ecological flood pools, while water consumption is increased. Ecological water circulation is enhanced through permeable ground paving, moisture-proof ecological wall surfaces, and landscape flower ponds.

Keywords: rural architecture, ecological nature, plants, rainwater, rammed earth walls.

INTRODUCTION

Rural residential courtyards, as an important component of rural ecosystems, have a long history of construction both domestically and internationally. Courtyard planting is a traditional agricultural culture and an inherent way of life in rural areas. The diverse spatial forms of scattered planting courtyards are an important part of the vegetation landscape in rural settlements, with a wide range of ecosystem services. In recent years, there has been increasing attention from scholars in China on the study of residential environments, particularly the relationship between residential courtyards and villages, towns, and settlements(张玉魁, 2020). However, there has been relatively less focus on the study of the small-scale environment of residential courtyards. The various shapes, sizes, and compositions of thousands of households' gardens form the main vegetation landscape in rural settlements, preserving a variety of plants in household gardens. These gardens can provide abundant products, maintain ecosystem resilience, and have extensive ecosystem services(Zhang & Chen, 2015). Therefore, the study and conservation of garden plant diversity have received increasing attention from researchers, especially ecologists and ethnobotanists. The study of garden plant diversity composition, influencing factors (Yuan et al., 2022) and ecosystem service functions has become a current hotspot (J. Wang et al., 2022).

The scarcity of freshwater resources in the Xi'an region is becoming increasingly prominent, with the Northwestern region accounting for only 10% of the country's water resources. The Guanzhong region experiences three dry seasons and heavy rainfall in the summer, with uneven temporal and spatial distribution of precipitation, resulting

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in overall water scarcity(J. Wang et al., 2022). Against the backdrop of rapid urbanization in China, the spatial form of residential areas in Guanzhong is showing a trend towards concentration, water usage patterns are becoming more complex, and sewage discharge is increasingly relying on piped drainage methods. This has led to issues such as inefficient rainwater collection and utilization, lack of drainage hierarchy, poor durability of water-related facilities, disruption of hydrological cycles, and a lack of systematic water-related infrastructure. The development-environment conflict is intensifying, making water conservation actions urgent. In order to alleviate this conflict, research on ecological water-saving construction techniques for residential areas in Guanzhong is particularly important.

Nandoujiao Village is located on the southern edge of the Guanzhong Plain in Shaanxi Province, China(孙文君;刘媛;郭珊珊;, 2018). It has a flat terrain and convenient transportation, with abundant human resources (Figure 1). Formerly known as Nandoujiao Village (now part of Dujiao Town), it is a village with a long history and rich cultural heritage. It is situated at the foot of the Qinling Mountains, southwest of Ziwu Town in Chang'an District of Xi'an City. It is adjacent to the Ziwu Town Office and is located 45 kilometers away from Xi'an City. It is situated on the third level terrace of the Wei River and is the last village on the way from Guanzhong to Ziwu Ancient Road. Therefore, it is also known as the "millennium ancient village guarding the northern entrance of Ziwu Road." In 2018, Nandoujiao Village, Beidoujiao Village, and Xicun were merged into one administrative village named Nandoujiao Village. Since the main village observed and surveyed was Nandoujiao Village, it will be referred to as such below. The village covers an area of approximately 60 hectares, with a population of over 1500 people. Public facilities include primary schools, kindergartens, village committees, cultural activity squares, and clinics.

Nandoujiao Village has a temperate monsoon climate, with an average annual temperature of 6 to 13°C. The coldest month is usually January, with an average temperature around -5°C, while the hottest month is typically July, with an average temperature of around 30°C. The annual precipitation ranges from 500 to 800mm, with 60% occurring from June to September. Rainfall during this period is often in the form of short-duration heavy rainstorms, while winter and spring experience relatively less precipitation. Spring and summer droughts are common in the region.According to local elders, Ziwu Ancient Town is the last town on the route from Guanzhong into Ziwu Ancient Road. Nandoujiao Village, located at the mouth of Ziwu Ancient Road, is a necessary passage for travelers entering or leaving the road. In the past, those who traveled to and from the southern mountains (through Ziwu Road, transporting and selling goods between southern Shaanxi and Guanzhong) would cross the steep mountains and valleys, and upon leaving Ziwu Valley, they would reach the quaint city gate and the neatly arranged inn of Nandoujiao Village. Nandoujiao Village was once prosperous in history, serving as an important node on the Ziwu Ancient Road where many travelers, going north or south, would rest. The village has a rich cultural heritage, and remnants of buildings from different eras can still be found. However, due to the migration of residents, the old village has fallen into disrepair. Many houses have collapsed or been abandoned, but the traditional architectural style of the Guanzhong region, characterized by courtyard houses, can still be seen.

Figure 1: Nandoujiao Village is located on the southern side of Xi'an City, Shaanxi Province, China. It is situated on a plain, with the Qinling Mountains to the south. It is a village with a long history. The inner part of the village is the old village, while the outer part is the new village.

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METHODS

A. Methods of data collection

1. Field research method. This method involves conducting extensive research and visits to collect relevant information about the research subjects. During the field research process, detailed and comprehensive understanding of the natural environment, village layout and form, historical relics, as well as local customs, and historical culture of the village are obtained through methods such as recording, filming, and photography.

2. Literature review method. This method involves reviewing existing domestic and foreign literature, relevant books, journal articles, etc., to gain a comprehensive and systematic understanding of the current research status both domestically and internationally. The collected data is then organized and summarized to form a theoretical framework and gain insights into the current issues of ecological water conservation in Guanzhong's residential architecture. By utilizing library resources and the internet, relevant theoretical research and practical case studies on the protection of ancient villages both domestically and internationally are collected and analyzed, providing sufficient literature for in-depth research.

B. The methods of data analysis.

1. Comparative analysis method. During the initial stage of comparative research, emphasis is placed on comparing and studying the methods and theoretical applications of domestic and international research on the preservation of historical villages, using relevant disciplinary approaches. In-depth analysis and comparative studies are conducted on ancient villages that have similar backgrounds, village forms, and environments to the research objects. Considering the current status of the relevant preservation and development of the research objects, a suitable, feasible path for preservation methods that allows for sustainable development needs to be identified.

2. Case study method. This paper classifies traditional villages in the Guanzhong area and selects representative individuals from each category of traditional villages for analysis. Characteristics are summarized to provide reference for future studies on traditional villages of the same category.

3. Historical analysis, induction, and deduction method. The formation of traditional villages is not a process that happens overnight; it is a long and evolving dynamic process. This paper combines field surveys and literature review findings to analyze the formation process of typical traditional villages from the perspective of development and change. This analysis aims to summarize the commonalities and individualities of traditional village spatial forms.

RESULTS

1. Architectural design, rammed earth walls

1.1. Architectural form and layout

The traditional culture of the Guanzhong region has influenced the residential architecture of Nandoujiao Village. As a result, the residential buildings in Nandoujiao Village adhere to the basic architectural forms and spatial layouts commonly seen in the Guanzhong region. The roads form a vertical grid pattern, and the houses are arranged along the streets or lanes, with small alleys leading to the households. The houses are closely clustered together, forming a cohesive community(冯书纯, 2015). The architectural complex exhibits a strong defensive and inward-oriented character (Figure 2). The layout follows the traditional style of narrow courtyards in the Guanzhong region's rural residences (赵航, 2016). Additionally, influenced by the natural climatic conditions of the Guanzhong region, the summer heat is generally unbearable, which profoundly affects the layout and form of residential buildings in Nandoujiao Village. The majority of the traditional houses in Nandoujiao Village adopt a slope-roofed style. To cope with the scorching summer, over time, the courtyard layouts of these old houses have evolved into narrow and elongated north-south courtyard structures. This design allows the courtyard to effectively avoid excessive sunlight, creating large shaded areas(罗磊;王子佳;黄庆涛;马骁潇;, 2023), providing a cool refuge for the people within the courtyard (Figure 3).

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The Guanzhong region, due to its geographical and climatic advantages, has been the birthplace of agricultural civilization since ancient times. Folk beliefs in this region are deeply influenced by its history, cultural legends, and geographical environment, resulting in a profound worship and reverence for deities and nature(Zhu, 2012). Inherited from Fengshui culture, the orientation of courtyards and the surrounding landscape in Nandoujiao Village are carefully considered, as the residents hope to arrange and construct their homes according to the traditional Fengshui customs to bring good luck and blessings to themselves and the entire village (刘麟鼎;, 2019). Representative courtyards in Nandoujiao Village are mostly concentrated in the old residential area, with some having a history of several decades or even hundreds of years. Among these courtyards, some are now mere remnants with only the courtyard space left, but their overall layout and spatial forms are relatively intact. Others have retained only the rooftops or foundations, having lost their original architectural forms and layouts. A few courtyards still preserve their complete building structures, though some components have suffered significant damage. Despite the varying degrees of completeness exhibited by these courtyards, they all possess a certain level of representativeness.

The old residential buildings in Nandoujiao Village predominantly utilize locally available materials from the natural environment, emphasizing the use of local resources to retain the rural atmosphere. The construction and form of these buildings focus on the combination of earth and timber structures. Some houses are built with brick and timber frames, while others are constructed with earth and timber structures (Figure 2) (Wu, 2013). The majority of the roofs in these residential buildings are covered with small tiles, with some areas using barrel tiles, and green tiles with interlocking joints are used at both ends. The rooftops are adorned with brick carvings, and the tiles form intricate hollow decorations (Figure 3) (Ao, 2012). The interior space of the residential buildings consists of basic spaces such as the living room, bedrooms, kitchen, and dining room. The living room, serving as a private space for various activities, is integrated with the bedrooms. In most residential buildings in the Loess Plateau region, there is no separate living room space. Instead, the living room and bedroom are often merged together, creating a stronger sense of privacy in these spaces. Typically, they serve as reception areas for important or close guests.

Figure 2: The architectural complex exhibits a strong defensive and inward-oriented character, representing the traditional narrow courtyard residential form of the Guanzhong region. The materials used mostly come from the local natural environment, emphasizing the use of locally available resources for cooling purposes.

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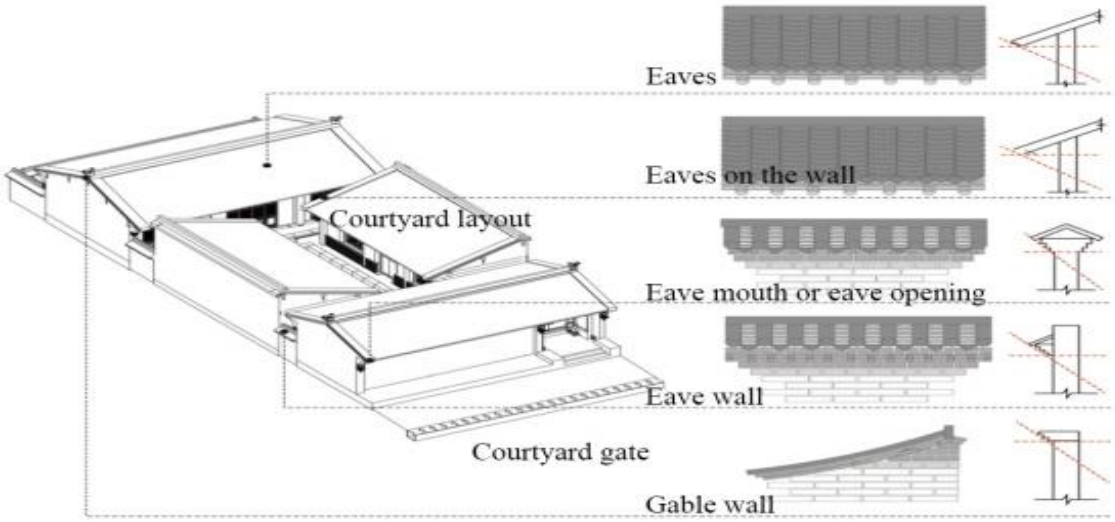

Figure 3: The courtyard layout forms a narrow and elongated north-south inner courtyard structure during construction, which is used to avoid sunlight and heat in the summer. The roofs are covered with small tiles, with some areas using barrel tiles, and green tiles with interlocking joints are used at both ends. The rooftops are adorned with brick carvings.

1.2 Rammed earth walls

Rammed earth walls are a traditional building structure primarily composed of compacted soil and stones. Due to their low cost, they are commonly found in rural areas of central and western China with dry climates and abundant soil, including in Nandoujiao Village, where they are extensively used (王赟;张波;, 2010). Earth construction is advantageous as it allows for on-site sourcing of materials, is reusable, and has low cost while offering excellent insulation and thermal properties. After the collapse or demolition of the soil walls, they can return to the land, aligning with the principles of environmental sustainability. Rammed earth construction has a long history in China. Rammed earth is a material formed by mixing soil and water, which, when compacted and cured, forms a sturdy wall. The construction process typically involves mixing soil and water, followed by repeated pounding with wooden rammers or hammers to tightly compact the soil and create a solid wall. Rammed earth walls have the advantage of excellent insulation and soundproofing properties, while also regulating indoor humidity and temperature. Additionally, they exhibit good durability and seismic resistance.

However, with the development of modern construction technology, the use of rammed earth walls has gradually decreased. This is because the construction process of rammed earth walls is relatively complex and requires a significant amount of manpower and time. Additionally, the seismic resistance of rammed earth walls is relatively poor and cannot meet the seismic requirements of modern construction standards. Despite this, rammed earth walls are still used in specific building projects, especially when aiming to preserve traditional culture and architectural styles. Moreover, some research efforts are dedicated to improving the seismic performance of rammed earth walls, making them more suitable for the demands of modern construction.

The construction process of rammed earth walls can be summarized in several steps (Figure 4):

① Site selection and material preparation

Generally, a site with open and flat terrain is selected. After preparing the site, materials needed for construction are gathered, such as stones, wood, bamboo, and soil. These materials are usually sourced locally. Stones for building the foundation are obtained from nearby mountains, selecting those with regular shapes, appropriate sizes, and high strength. Previously, vines were used as wall reinforcement material due to their exceptional strength, but nowadays, bamboo strips are more commonly used, selecting bamboo with a thickness similar to that of a thumb. Suitable soil

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is chosen as the raw material for rammed earth walls, typically clay or soil with high clay content. The soil needs to be screened and purified to ensure its quality and purity.

② Building the foundation and making molds

The foundation for local rammed earth walls is constructed using rough stones with relatively regular shapes, appropriate sizes, and high strength. These stones are dry stacked in a single layer directly on the prepared and leveled site, without the use of cement mortar or other binding materials. The height of the foundation depends on the size of the stones and is generally around 300mm. The image shows the constructed foundation made of rough stones. In local soil wall construction, the "block construction" technique is used, and the molds used are inexpensive and effective rammed earth molds made by farmers based on their long-term experience. These molds can be reused multiple times.

③Compacting the soil: Using tools like a ramming hammer or ramming rod, the mixed soil is compacted within the building mold or wall frame. The compacting process involves repeatedly pounding the soil to tightly arrange it and form a solid wall. Each layer of the wallis approximately 330mm high. After completing the first layer of the entire wall, the process is repeated to start constructing the second layer of the wall.

④ Layered compacting: The construction of rammed earth walls typically follows a layered compacting approach. After compacting each layer of soil, a layer of stones or bricks is added to enhance the stability and strength of the wall. Generally, a circle of reinforcement is placed between several layers of the wall. This reinforcement consists of two straight bamboo strips, approximately 40mm wide, acting similar to steel bars in a reinforced concrete beam. This process is repeated in a cycle until all the walls have been compacted.

⑤ Smoothing the wall surface: After the construction of rammed earth walls is completed, it is necessary to smooth the wall surface to enhance its aesthetic appearance. Tools such as a scraper or trowel can be used to even out the surface of the wall.

It is important to note that the construction techniques of rammed earth walls may vary based on geographical location and specific requirements. During the construction process, consideration should be given to drainage and moisture prevention measures for the walls, as well as insulation and soundproofing treatments. Additionally, safety precautions should be taken to prevent accidents such as soil collapse or wall collapse.

Figure 4: Construction process of rammed earth walls: site selection and material preparation; building the foundation, making molds; compacting the soil; layered compacting; smoothing the wall surface. During the construction process, it is necessary to consider drainage and moisture prevention measures for the walls, as well as insulation and soundproofing treatments. Safety should also be ensured.

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2. Plants

2.1. Choosing Suitable Plant Species

Nandoujiao Village is located in a warm temperate semi-humid forest region(管文娜, 2019) within the humid residential greening area of the western Henan Basin. Its northern boundary extends along the line of Licheng, Lingshi, Hancheng, Fuping, and Baoji, including the northern foothills of the Qinling Mountains, the Guanzhong Plain, southeastern Shanxi, and northwestern Henan (Table 1). The annual precipitation ranges from 500 to 700mm, with a dryness index of 1.3 to 1.5. The average annual temperature ranges from 12.5 to 14.5°C, with accumulated temperatures above or equal to 10°C ranging from 4000 to 4900 hours. Nandoujiao Village is the warmest and most humid area in the entire region(X. Wang et al., 2013). The complexity and diversity of plant species and vegetation types are also evident. In such an environment, the tree species used for residential greening are not only abundant but also economically valuable, which meets the economic demands of the residents (穆森;刘媛;朱雨朦;, 2018). Examples of fruit trees include persimmons and chestnuts in the Guanzhong region, and Chinese toon, kiwi, paulownia, Chinese scholar tree, and catalpa trees in the northern foothills of the Qinling Mountains.

Nandoujiao Village possesses a considerable amount of plant resources, providing numerous options for plant species for residential courtyard greening. Considering the particularity of residential greening, the selection of plant species takes into account their adaptation to the climate(陈欣;, 2020), as well as the preferences and habits of the residents (Figure 5).

Table 1: Climate characteristics of Nandoujiao Village and plant species suitable for the climate

Climate zone	Coldest month average temperature	Hottest month average temperature	Annual precipitation/mm	Soil
Warm temperate semi-humid forest zone	-3℃ ~ 0℃	23℃ ~ 29℃	500-650, mountainous areas reach 700-800	Brown soil
Commonly used green plants for residential landscaping				
Phoenix tree, Paulownia tree, Chinese toon tree, Chinese mahogany tree, Spruce tree, Bigleaf boxwood, Rose, Persimmon tree, Black locust tree, Walnut tree, Ivy, Horse chestnut tree, Lilac, Crepe myrtle, Peach tree, Pine tree, Pomegranate tree, Groundcover, Silk tree, Chinese scholar tree, Catalpa tree, Poplar tree, Osmanthus tree, Bamboo, Sichuan pepper tree, Willow tree, Elm tree, Pear tree, Quince tree, Kiwi fruit, Fig tree, Mimosa tree, Cypress tree, Honeysuckle.				

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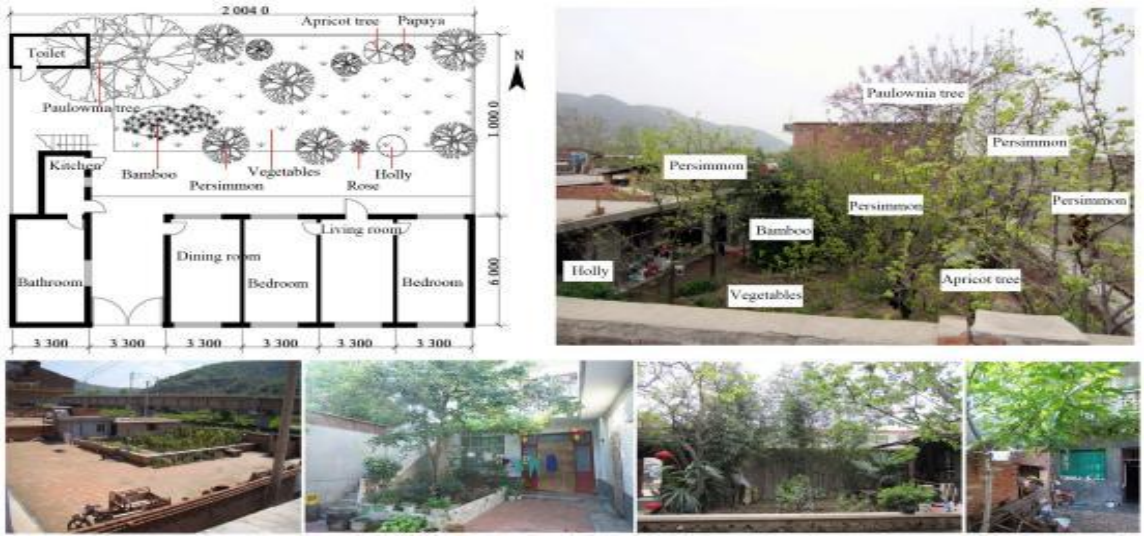

Figure 5: Plant categories in typical courtyards of Nandoujiao Village, fully meeting the economic demands of the villagers for plants.

Jia Wenna and Lei Zhendong, professors from Xi'an University of Architecture and Technology（菅文娜;雷振东;, 2016), conducted a detailed statistical analysis of the demographic characteristics, average household income, income sources, and non-agriculturalization level of 68 individuals from 20 households in Nandoujiao Village. They also collected data on the planting area and composition of plants in 20 courtyards (Table 2). The results indicate that the labor force under the age of 40 accounts for only 20.6%, suggesting that courtyard managers are predominantly elderly. Moreover, there is a scarcity of labor in the village, leading to a higher proportion of perennial plants in the courtyards. The proportion of households with an average monthly net income above 3000 yuan is similar to the proportion of ornamental courtyards, while the proportion of households with an average monthly net income below 2000 yuan is comparable to the proportion of economically-oriented courtyards. This indicates that household income significantly influences the types, composition, and diversity of plants in the courtyards.

Table 2: Climate characteristics of Nandoujiao Village and plant species suitable for the climate. Due to low income levels, there is a high demand for economically viable plant species in the village. Residents prefer tree species that are affordable and produce fruitful results.

Research project	Reference factors	Effective sample size (households)	Number of characteristic samples (households)	Percentage distribution
Planting area	Below 2 ㎡	20	2	10%
	2-5 ㎡	20	8	40%
	5-15 ㎡	20	7	35%
	Above 15 ㎡	20	3	15%
Plant type	Economic type	20	11	55%
	Ornamental type	20	3	15%
	Mixed type	20	6	30%
Configuration form	Emphasizing landscaping	20	3	15%
	Random planting	20	17	85%

2.2.Combination patterns of low-growing plants and shade trees around residential buildings.

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For planting arrangements, combining appropriate shade trees not only enhances the ecological shading benefits but also has a certain impact on the wind environment around residential buildings during winter and summer seasons. The branching height of commonly used shade trees in residential areas is generally around 5 meters, which is not ideal for shading the low-angle summer sun. By combining low-growing plants, this drawback can be mitigated, improving the shading effect on the walls of the buildings (Figure 6). For Nandoujiao Village, which requires protection from cold winds in winter, as it is located in a cold region, winter insulation is necessary. In these areas, the issue of blocking cold winds during winter in residential areas needs to be considered. Therefore, a good combination of low-growing plants and tall trees can yield positive results. The integration of plants with the layout of buildings and the village can effectively block cold winds.

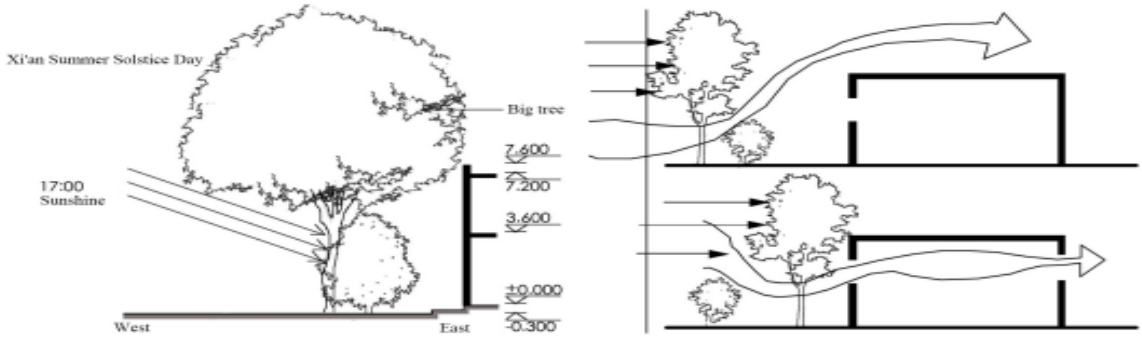

Figure 6: The combination of shrubs and trees in the courtyard layout of Nandoujiao Village can provide shade during the hot summer, creating a comfortable and cool environment under the trees. It also ensures the flow of fresh air and wind movement.

2.3. The synergistic arrangement of plants and residential buildings

The objective of residential courtyard greening design is to create a comfortable microenvironment within the courtyard while ensuring that it does not interfere with the usage of the space and adheres to the planting customs of residential areas. It primarily utilizes the shading effect of shade trees to reduce direct sunlight, providing shade for buildings and courtyards without compromising the sunlight requirements during winter. When scientifically planting vegetation around residential buildings, three main factors are considered: the orientation of the plants relative to the buildings, the distance between the plants and the buildings, and the size and type of the plants themselves, all of which contribute to the spatial arrangement of the courtyard (Figure 7).

The principles of residential courtyard greening design are based on the fact that the size and physical attributes of plants are not restricted by surrounding interfaces. Therefore, available spaces within and outside the residential courtyard can be utilized for planting tall trees, which play an important role in residents' activities. Plants can provide shading for indoor and outdoor spaces, reducing direct sunlight during the summer. From this perspective, the surrounding environment of residential areas can be divided into three scales: courtyard, expanded courtyard, and cluster of courtyards. Planting in these three scales can establish a symbiotic relationship with residential buildings, requiring the selection of suitable plant species and scientific determination of the distance and orientation of the plants relative to the buildings (Figure 7).

In the loess plateau region where Nandoujiao Village is located, the optimal branching point height of tall shade trees commonly used in residential areas is generally around 5 meters. This height is not ideal for shading the low-angle summer sun. However, this drawback can be mitigated by combining low-growing plants, improving the shading effect on the walls of the buildings (Figure 8). The courtyard space is spacious, allowing for activities such as cooking and dining in the external courtyard space during comfortable seasons or favorable environmental conditions. In closely clustered village layouts, some residents enjoy sitting in front of their homes or visiting neighbors while holding their bowls for meals and engaging in conversations. Traditional rural customs also involve hosting guests during wedding and funeral events, which significantly impact the utilization and influence of the main house, courtyard, and front yard spaces in the residential compound.

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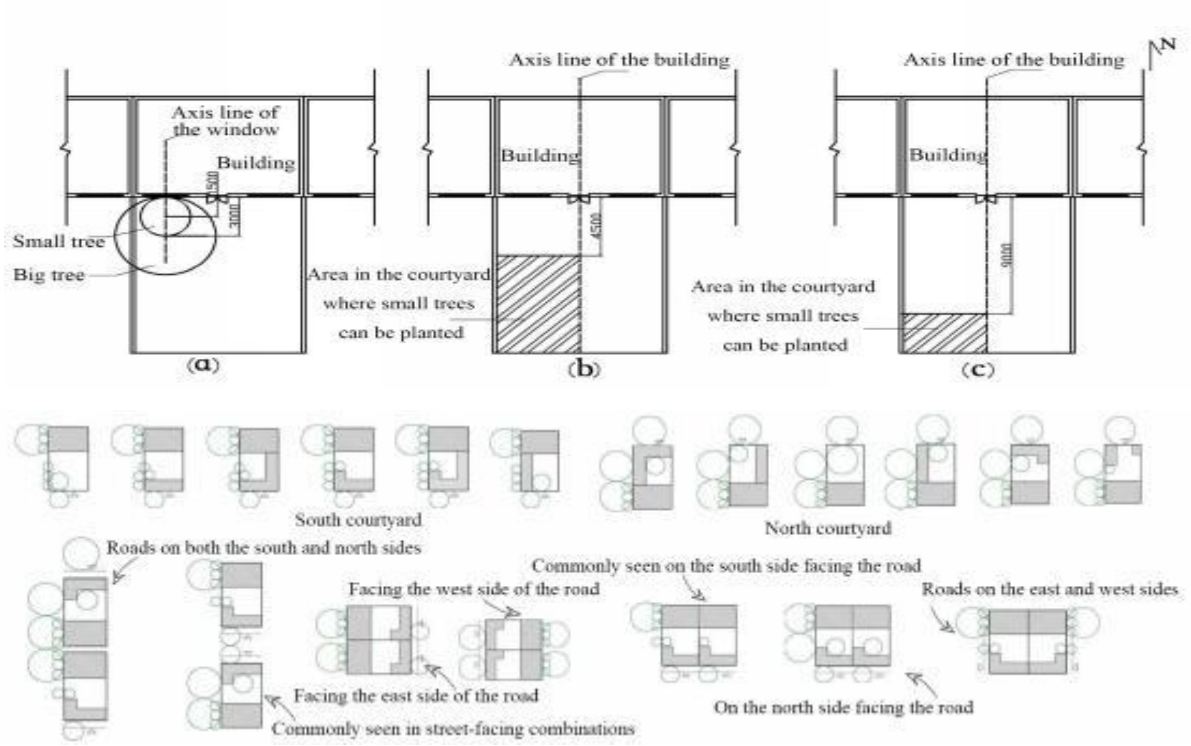

Figure 7: The upper image shows the optimal distance and position for planting south-facing residential buildings. The lower image depicts the optimal layout pattern for buildings and plants in a typical residential compound space.

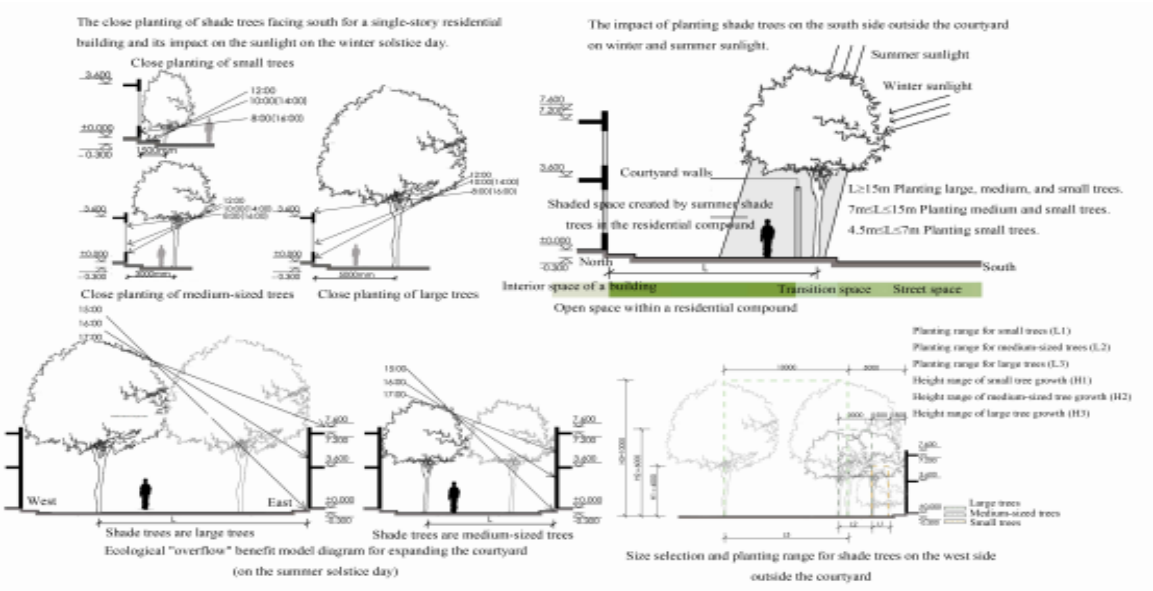

Figure 8: The upper image illustrates the impact of closely planted south-facing shade trees on the sunlight during the winter solstice for single-story residential buildings. The image below shows the influence of south- facing shade tree planting outside the courtyard on sunlight during winter and summer seasons. The diagram demonstrates the ecological "overflow" benefits of expanding the courtyard. Lastly, the selection of shade tree sizes and planting range on the western side outside the courtyard is depicted.

3. Drainage, Water Storage, and Ecological Water Circulation

In Nandoujiao Village, the traditional residential courtyard buildings along the central axis mostly have double-sloped hard-tiled roofs with upturned eaves. Rainwater starts from the roof tiles and flows into the courtyard's

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drainage ditch through drip edges or eaves, with half of it directed towards the streets and alleys. The east-west wing buildings have inward sloping single-sloped hard- tiled roofs, and the adjacent roof ridges are connected, directing all rainwater to the courtyard. This design emphasizes the concept of not letting valuable resources flow out to others' fields. Generally, the east wing buildings are higher than the west wing buildings. In Nandoujiao Village, there are also courtyards with corridors, and the east-west wing buildings have colonnades. Walking around the corridor during rainy days prevents getting wet, while during sunny days, the overhanging eaves provide shade from the sun. The roof slope is set at 25%-30%, allowing for rapid drainage of rainwater and reducing the roof's load. The roof adopts an unorganized drainage system, and the overhanging eaves protect the walls from water erosion.

"Four eaves and eight water drips" is a characteristic feature of housing in Nandoujiao Village. The connecting parts between the main house and the wing buildings, as well as between the wing buildings and the entrance buildings, are equipped with four small roof eaves to collect rainwater, known as "dongcao" (吴艺婷, 2021). The sloping roofs of the main house, entrance buildings, or east-west wing buildings are designed for drainage. The rainwater from the sloping roofs flows along the small eaves and into the courtyard. This design serves multiple purposes: it prevents water intrusion into the walls of the wing buildings and the foundation of the connecting parts, thus increasing the lifespan of the houses. Additionally, it acts as a buffer during heavy rain, ensuring a clear and gradual drainage system.

The eaves at the roof edge of the buildings extend layer by layer outward and are used for the front and rear eave walls, gable walls, courtyard walls, entrance walls, and the lower edge of the roof, serving the function of protecting the lower walls from the erosion caused by rainwater. The top of the courtyard walls is constructed with a wall cap, either by setting up eaves or using green bricks to stack and protrude from the wall surface, preventing the courtyard walls from being soaked and eroded by rainwater. The top of the gable walls is constructed with brick lines that protrude 2-8cm, increasing the depth of the eaves, and taking on the role of roof drainage and preventing water from splashing against the side walls, thus preventing rainwater from wetting the gable walls.

The fundamental purpose of extracting traditional ecological wisdom (Figure 9) is to explore how traditional folk houses in the Guanzhong region have responded to the local arid climate during their formation process over thousands of years. This can be summarized into three aspects: the first is to enhance the recycling of water resources, the second is to increase available water volume, and the third is to reduce water loss (Table 3). The characteristic rainfall climate in the Guanzhong region has not changed, thus, when choosing modern application strategies, the same approach can still be used while incorporating innovative water-saving techniques. Enhancing ecological water circulation in traditional folk houses is manifested in permeable ground paving, moisture-resistant ecological wall surfaces, and landscape water pools. Increasing available water volume in traditional folk houses is demonstrated through water cisterns, water wells, and ecological flooding pools (Table 4). Enhancing the coherence of water-related facilities in traditional folk houses is shown through roof water collection and gutter components for water diversion.

Table 3: Ecological Water Principles in Nandoujiao Village: Rapid Drainage, Increased Water Storage, and Ecological Water Circulation.

serial number	Drainage measures: Strengthen drainage	Water storage measures: Increase available water volume	Increase ecological water circulation
1	Roof runoff	Water cistern	Permeable pavement
2	Eaves component water diversion	Water well	Moisture-proof ecological wall
3	Channel drainage	Ecological flood detention pond	Landscape flower pond

Water storage facilities serve the purpose of regulating water quantity. Storing rainwater during the rainy season helps prevent the loss of precipitation resources, reduces pressure on groundwater extraction, mitigates short-term runoff, and prevents flood disasters. The stored rainwater can be used for domestic and agricultural purposes during the dry season. Water wells, commonly used in the Guanzhong region, collect and store natural rainfall or winter

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snowmelt. In areas with low groundwater levels and limited well drilling capabilities, reliance on rainwater is crucial for meeting production and livelihood needs (Table 4). Rainwater flows naturally along the slope of the courtyard floor into a sedimentation tank located near the water well. It undergoes sedimentation and filtration before entering the water well. Once the water level reaches capacity, the water flow is blocked, causing the excess rainwater to overflow into infiltration pits. Utilizing water wells for storing and purifying rainwater is an important and effective solution for addressing water supply issues in arid and semi-arid regions of Northwest China. It offers advantages such as low cost, long usage life, and simple operation.

In the past, traditional residential buildings were constructed using locally available materials, and the most widely used material was yellow clay, which was used to produce a large number of water jars (Table 4). Water jars made from yellow clay are heavy, sturdy, and durable. They have a circular cross-section, tapering from a larger opening at the top to a smaller one at the bottom, facilitating easy pouring and rolling. The bottom and top of the water jars are left unglazed, allowing for good air permeability, which ensures that water can be stored for extended periods without spoilage. When water is needed, it is scooped using a ladle. The water jars are covered with wooden lids, with smaller water containers having a single piece of round wooden cover, while larger ones have two semi-circular wooden covers, allowing for easy access by opening only one half at a time. Some water jars are placed in the central courtyard, serving as temporary firefighting water sources or for nurturing landscape vegetation. Others are positioned directly beneath the eaves to collect rainwater from the roof, ensuring a backup water supply. Additionally, some water jars are placed in the kitchen for storing domestic water.

Floodwater storage ponds, listed in Table 4, serve as both drainage facilities and precious water landscape features in the village. They provide non-potable water for villagers' daily needs and firefighting purposes. These ponds play a crucial role in water storage, flood regulation, irrigation, domestic water supply, and improving the ecological environment. They serve as the water supply center of the village and also function as a gathering place where people can freely interact. Villagers gather at the ponds to seek shade, engage in leisurely conversations, and women often use the ponds to do laundry.

Table 4: Water Storage Measures: Water Jars, Water Wells, Floodwater Storage Ponds.

Water storage facilities	Materials	Morphology	Location relationship	Function
Water jar	Loess soil	Inverted conical shape, larger on top and smaller at the bottom	Directly under the eaves, in the center of the courtyard, in the kitchen, inside the house	Firefighting and plant cultivation
Water cellar	Red loam soil, stone materials	Cylindrical, shuttle-shaped	In a lower and hidden area of the courtyard	Provides water for daily life and production
Flood pond		Hemispherical shape	Located in low-lying areas near the village	Used for irrigating farmland and providing water for livestock and daily washing
Name		Water jar	Water cellar	Flood pond

Node diagram

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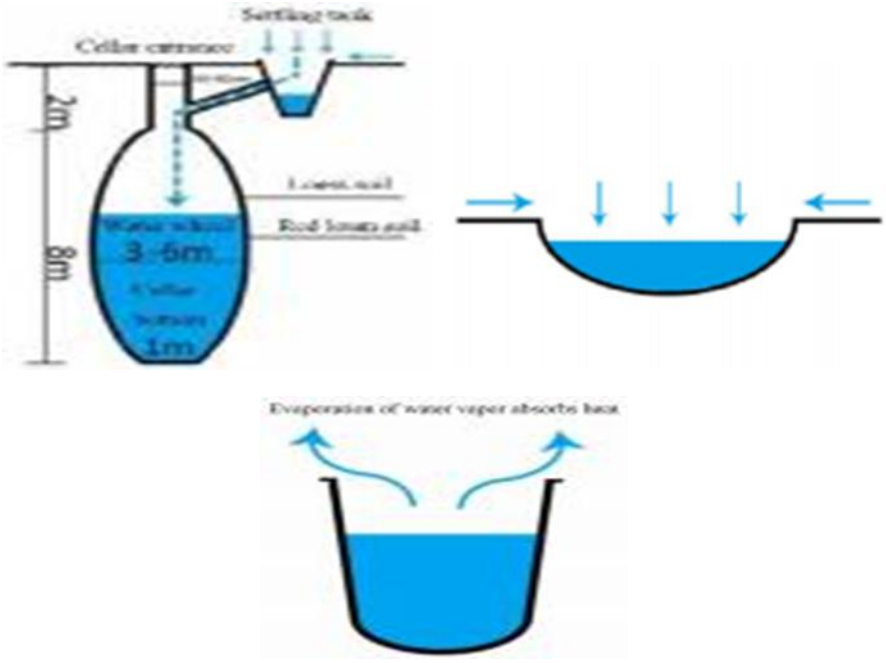

Photo of the actual scene

Through the analysis of traditional ecological water-saving techniques in Nandoujiao Village's folk houses, five architectural water-saving design concepts have been summarized: the concept of multi-purpose water circulation, the concept of hierarchical water collection, the concept of prioritizing water storage, the concept of micro water circulation, and the concept of self-balancing water usage. Due to the complexity of water demands and the concentration of spatial layouts, when drawing from traditional ecological water-saving wisdom, we should not simply imitate, but rather learn from their methods of dealing with arid climates. We need to analyze the contradictions between traditional wisdom and modern construction and explore the connection between traditional ecological water-saving wisdom and modern applications. By doing so, we can discover ways and methods to integrate traditional ecological water-saving wisdom with modern residential buildings, infusing them with new vitality.

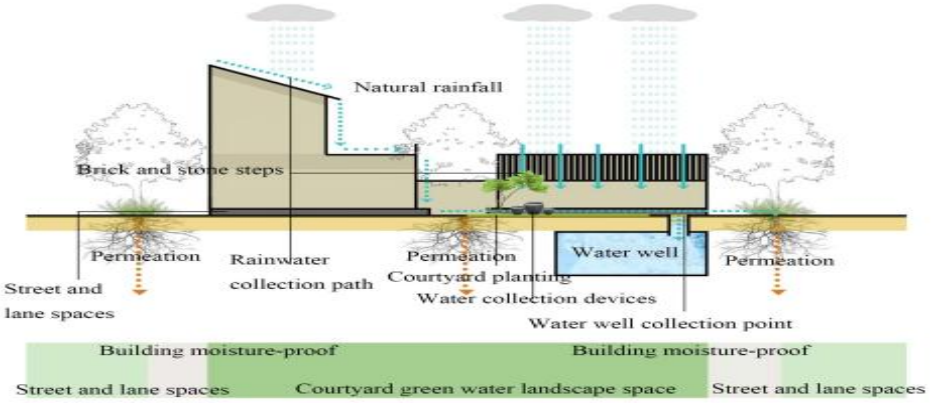

Figure 9: Indirect Rainwater Utilization Model in Nandoujiao Village Courtyards: Courtyard Drainage, Courtyard Water Storage, Courtyard Ecological Water Circulation.

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DISCUSSION

The buildings in Nandoujiao Village, Xi'an, possess strong ecological characteristics. The materials used in the construction of the old residential buildings mostly come from local natural resources. Rammed earth walls provide an economical, environmentally friendly, and sustainable building material and technique, effectively protecting the structures from natural disasters, temperature fluctuations, and noise pollution. The architectural complex exhibits a strong defensive and inward-oriented design. The narrow and elongated north-south courtyard layout helps to mitigate excessive sunlight during the summer, creating large shaded areas and a cool courtyard environment.The vegetation in Nandoujiao Village demonstrates strong adaptability to the local climate. The selection of tree species takes into account the residents' needs and habits, with cost- effectiveness being the most important criterion. The combination of low shrubs and shade trees surrounding the residential buildings not only enhances the ecological shading benefits but also optimizes the wind environment around the houses.The indirect rainwater utilization model in Nandoujiao Village courtyards includes courtyard drainage, courtyard water storage, and courtyard ecological water circulation, presenting a harmonious pattern of rainwater utilization and storage. The water storage measures primarily consist of water jars, water wells, and floodwater storage ponds, catering to the diverse water needs of different users.

Due to relatively low economic levels and limited resources in rural areas, the development of rural architecture is somewhat constrained by economic factors. In the past, even with limited economic conditions, some rural areas were able to use simple and practical building materials and techniques, which objectively improved the livability and durability of the buildings. However, with the advancement of rural development in China, rural construction is now progressing rapidly. China is actively undertaking poverty alleviation tasks, and rural development has become one of the country's key priorities. With the comprehensive revival of the Chinese market economy, rural development will receive more attention and support.The popularization of technology and new materials is an important direction for rural construction. With technological progress, new building materials and techniques continue to emerge, providing better insulation, soundproofing, fire resistance, and other properties, thus enhancing the quality and comfort of rural buildings. Moreover, the use of new materials can also reduce the consumption of natural resources and environmental pollution.

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